

ENHANCING GEOTECHNICAL INFORMATION WITH GROUND PENETRATING RADAR

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Abstract

To learn how well ground penetrating radar (GPR) can supplement or replace conventional test borings a research project was initiated through New Hampshire's State Planning and Research (SP&R) funding. The objective of the research was to determine if GPR could distinguish between and accurately determine the depth to different soil layers, bedrock, bedrock fractures, subsurface voids and river bottom profiles within different locations throughout New Hampshire. GPR profiles were obtained at locations between test borings or at locations where test borings could not be acquired because of time constraints or difficulties with drill rig access. To date, GPR has been used on a total of seventeen geotechnical projects as a supplement to the conventional test borings or as a sole source of subsurface information. This paper discusses the use of GPR on eight of these seventeen projects and includes projects where GPR was found to be very helpful, moderately helpful and projects where GPR was of little help. Included are the techniques employed for using GPR, and how the results were calibrated and verified.

Introduction

Bedrock depths are a concern when a geotechnical investigation is undertaken in New Hampshire. In many of our investigations the depth to bedrock can be deep on one section of the project, shallow on another and still variable on another. Over short lateral distances the depth to bedrock can change quite rapidly. By adding additional test borings time and money are quickly exhausted and subsurface interpretations can become more puzzling instead of less confusing. In addition, it's not always possible to add test borings because of environmental or access concerns. This leaves sections of a project having extremely difficult subsurface information to interpret or no information at all. Over the past couple of decades an exploration seismograph has been used to help fill in the gaps between our test borings. Although the information collected from this seismograph has helped on a number of our projects its use has been limited because it's a single station exploration seismograph.

It was determined that additional geophysical techniques should be employed to address the above concerns and to help prepare quicker and more accurate subsurface interpretations. By instituting a new non-destructive geophysical test method, subsurface data could be collected in areas between test borings or at locations where test borings could not be obtained, yielding better, faster and more cost effective subsurface interpretations.

Ground penetrating radar (GPR) was the geophysical device decided upon to help supplement our test boring data. GPR was tested using application procedures that would be characteristic of everyday use versus a highly controlled test project. In this way we could determine how well the information obtained by GPR could enhance our interpretations of subsurface conditions under typical project conditions. GPR was tested on seventeen geotechnical projects to determine if, where and how well GPR could work under varying site conditions. This paper highlights eight projects that are representative of our typical GPR deployments and demonstrate the degrees of success encountered.

Fundamental Concepts

GPR is a geophysical instrument that is nondestructive and produces a continuous cross-sectional profile of different subsurface features. It is often used to investigate subsurface conditions and features such as the depth to bedrock, different soil layers and subsurface voids. Subsurface profiles are

collected by towing the radar instrument over the ground surface and observing the underlying geologic features as profiles on a computer screen.

The electrical conductivity of the subsurface materials is one of two factors determining the depth to which the radar waves can penetrate. In low conductivity materials, such as dry sand or granite, deeper depths may be obtained. In highly conductivity materials, such as clay and shale, the radar waves are attenuated and absorbed, which greatly decreases the depth of penetration. The frequency of the radar antenna is the other factor determining the depth to which the radar waves can penetrate. Antennas with low frequencies (100 MHz) have lower resolutions but obtain reflections from deeper depths, about 10 to 30 meters, while higher frequency antennas (500 MHz) have greater resolution but less depth penetration.

GPR operates by transmitting pulses of radio waves down into the ground through an antenna. The transmitted energy is reflected from contacts between different earth materials. When the transmitted signal enters the ground, it contacts subsurface strata with different electrical conductivities and dielectric constants. Portions of the radar waves are reflected off a subsurface interface, while the rest of the waves pass through to the next interface. The digital control unit receives the reflected waves after they have returned through the antenna. The control unit registers the reflections against a two-way travel time, then amplifies the signals and sends them to a computer. The computer takes the output signals, representing reflected surfaces, and plots them on the radar profile as different color bands.

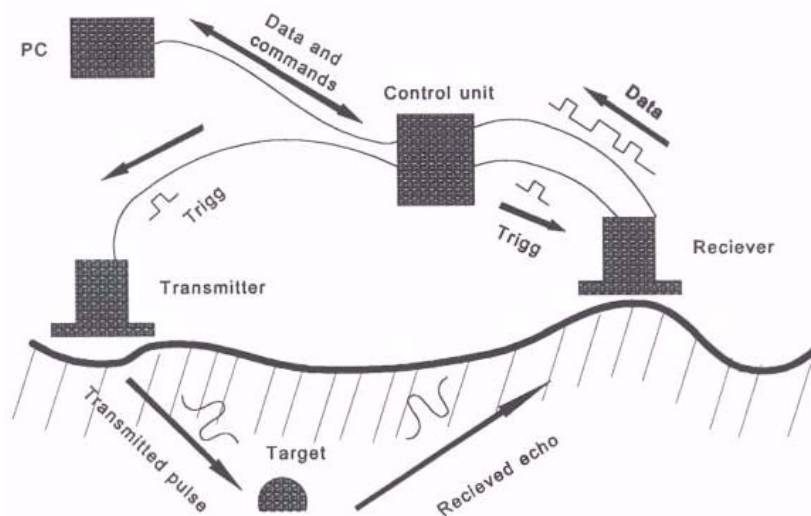


Figure 1: GPR schematic. The radar control unit is connected to a laptop computer through a parallel communications cable and to the transmitter and receiver through fiber optic cables.

Survey Design And Data Acquisition

For every geotechnical project, GPR data collection varies depending upon the existing subsurface information, accessibility, project plans and available control points. All geotechnical investigations have a set of project plans. Sometimes these plans are detailed and include accurate cross sections with survey stakes in the field. At other times, cross sections and survey are not available and the plans are very general or are old "as-built" plans with nothing more than a concept of what the new project entails. It is preferable to use GPR in conjunction with nearby test borings in such a manner where GPR can fill in missing data points between the borings. In order to obtain quality information over the shortest time period it is best to predict the depth to bedrock and the soil conditions ahead of time. This prediction will help make decisions about appropriate settings and antenna types when acquiring data.

When it's expected that bedrock will be encountered within the limits of the project, GPR can determine its depth by pulling the radar unit along the ground surface, parallel to the roadway's centerline at a predetermined offset. This data will provide a minimum of one data point on every cross section as

well as many data points at locations between the cross sections. In addition, the radar unit can be pulled over the ground surface perpendicular to the centerline along a specific cross section. This will yield a continuous profile along the entire length of that particular cross section.

When survey is not staked in the field, obtaining the depth to bedrock at any specific location on the project plans becomes a challenge. A determination as to where explorations should be conducted must be made based upon a geological reconnaissance, a review of the project plans, the availability of existing subsurface data, and the ease of GPR data collection. To track where GPR profiles, test borings and certain control points are located a Global Positioning System (GPS) is used to collect positional data points. By using computer aided design (CADD) or a geographical information system (GIS) the data points and lines collected by the GPS receiver can be plotted onto the project plans.

GPR profiles are acquired by clearing a path along the ground surface. This includes cutting trees and shrubs, leveling the ground surface and removing metal objects. The laptop computer and control unit are then strapped onto an individual and the antenna is pulled along the ground surface. On some occasions, the laptop computer and the control unit can be placed on the tailgate of a pickup truck and the antenna connected to the bumper and pulled slowly along the road. While obtaining profiles over the water everything can be placed in the bottom of a fiberglass boat and then driven over the water surface. A GPS can be used to track the distance traveled by the radar unit and positional data can be attached to the profile traces.

Equipment

The radar control unit used for this research project was a MALA GeoScience Ramac/GPR (MALA, 2000; RAMAC, 1999). Two antennas accompanied the instrument: a 500 MHz shielded antenna (Figure 2) and a 100 MHz shielded antenna (Figure 3). The 500 MHz antenna was used on shallow explorations and the 100 MHz antenna was used on deeper explorations. A Rocky II ruggedized laptop computer (Figure 4) ran the radar control unit (Figure 5) and displayed the profiles. A survey wheel (Figure 6) is attached to the rear of the antenna, which accurately tracks the distance traveled by the radar unit.



Figure 2: 500 MHz antenna



Figure 3: 100 MHz antenna



Figure 4: Laptop computer



Figure 5: Radar control unit



Figure 6: Survey wheel

When the survey wheel was unable to track the distance traveled, a Trimble GPS (Figure 7) was used. This was particularly useful for obtaining the locations of profiles collected over water. By collecting the positional data with the GPS, the locations of the profiles could easily be placed on the project plans. A laser profiler (Figure 8) was also used to help locate seams and fractures on the face of a rock cut and a digital camera (Figure 9) was used to help document pertinent project information.



Figure 7: Trimble ProXR GPS



Figure 8: Laser gun & profiler



Figure 9: Digital camera

Case Studies With Geophysical And Non-Geophysical Approaches

To operate the radar control unit and to display, filter and print GPR profiles the Ramac/GPR software program was utilized. Profile interpretations were made on the computer screen or from printed profiles. Of the seventeen projects that used GPR, the following eight projects represent our typical GPR deployments and demonstrate the degrees of success encountered.

Easton-Woodstock Roadway Project

Route 112 is a two-lane highway within the White Mountain National Forest (Figure 10). A project is proposed to resurface and straighten six kilometers of this highway. Test borings were conducted at several key areas of the project. One such area was approximately 300 meters of new roadway alignment that went into the woods, eliminating a large curve in the road. Six test borings were conducted along the new alignment. At locations between the test borings the depth to bedrock became a concern when the test boring data, the surface topography and the existing rock outcrops were all examined. GPR was deployed to address this concern and to determine the depth to bedrock within these areas (Figure 11). The test boring data revealed relatively clean sands and gravel over bedrock of varying depths. GPR profiles were collected over varied terrain with an outside temperature of 15°F (Figure 12). The 100 MHz antenna was used because the depth to bedrock was expected to be greater than four meters in many locations. Two profiles were collected parallel to the new alignment and four profiles were collected perpendicular to the new alignment, which would aid in drawing the bedrock lines on the project cross sections. Survey stationing had not been placed in the field so a GPS receiver was used to locate where the profiles had been collected and where the test borings had been conducted. The positional data for the test borings and the profiles were viewed on the project plans using ArcView GIS (Figure 13). Bedrock lines were drawn on the project cross-sections by correlating the profile and test boring data and by viewing their locations in regards to the centerline stationing on the project plans.

The radar profiles were calibrated using the test boring data by adjusting the velocity of the radar waves to match the depths at which the test borings intercepted the bedrock. Figure 14 is a GPR profile perpendicular to the roadway alignment, without topography correction, showing the interpreted bedrock line starting from the edge of pavement and going to boring B3. Figure 15 is the profile collected by pulling the radar unit from test borings B6 to B3, parallel to the roadway alignment. Boring B6 encountered bedrock at a depth of 3.4 meters, B5 at a depth of 3.4 meters, B4 at a depth of 1.2 meters and B3 at a depth of 4.0 meters. Both of these profiles demonstrate how GPR was able to provide detailed subsurface information in the areas between and adjacent to the test borings. This helped with the design of the cut slope over this section of the new roadway alignment.



Figure 10: Route 112, White Mountain National Forest



Figure 11: GPR unit fully assembled & being towed over the ground surface



Figure 12: Path through woods where GPR profile was collected

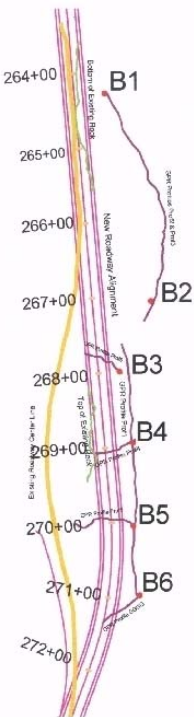


Figure 13: Map view showing test borings & GPR locations with both roadway alignments

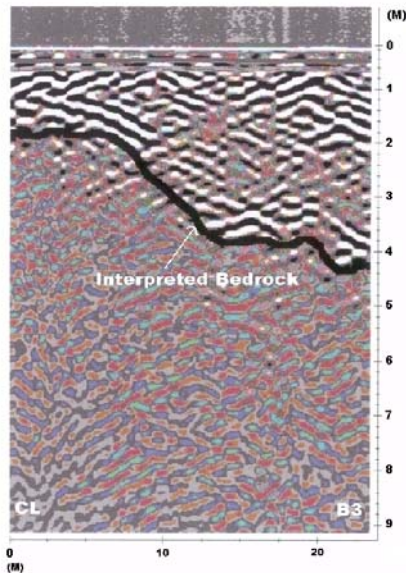


Figure 14: GPR profile, going from EOP to B3 perpendicular to the roadway alignment

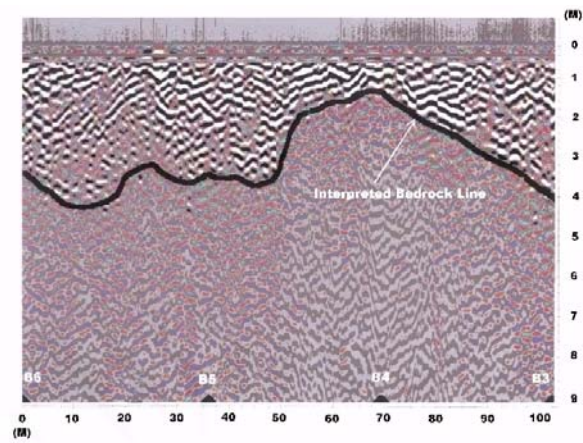


Figure 15: GPR profile between test borings B6 & B3, parallel to the roadway alignment

Windham-Salem By-Pass Project

A five-kilometer by-pass project in southern New Hampshire was another site where GPR was used to determine the depths to bedrock and to fill in gaps between the test borings. The profiles were collected after the test borings had been completed with a half a meter of snow covering the ground. The

geological site conditions were predominantly glacial till over bedrock at varying depths. Profiles were collected using the 100 MHz antenna at two separate locations, both of which were within the woods and on new roadway alignment (Figure 16). The first location was glacial till over deep bedrock and the second location was glacial till over shallow bedrock. At the first location, it was anticipated that the glacial till would absorb most of the radar energy, allowing for bedrock depths to be determined only where it was close to the surface. Additional test borings were required at this location and they were placed at positions where the radar unit indicated bedrock plunged to a deep depth. At the second location, the radar waves penetrated the full depth of the overlying till, allowing for bedrock depths to be determined throughout the new alignment. The GPS was used to track the location of where the test borings were conducted and where the GPR profiles were obtained.

Figure 17 is a radar profile collected from the first location along the new roadway alignment. At this location large roadway cuts of approximately 14 meters are proposed and accurate bedrock depths are required in order to make the appropriate roadway cut designs. At one end of the cut the test borings indicated that bedrock was relatively deep, approximately 17 meters, and at the other end of the cut they indicated it was relatively shallow, approximately 3 meters. The profile indicates that the radar waves were unable to penetrate the glacial till beyond a depth of approximately 4 meters. The only location where bedrock appears on the profile is where it rises above 4 meters in depth, which is along the last 15 meters of the profile. Three additional test borings were placed along this new alignment to confirm the depth to bedrock between test borings B104 & B213. Figure 18 is another radar profile collected from a different section of the new roadway alignment. Roadway cuts of approximately 6 meters are to occur in this area. At this location the bedrock is around 2 meters in depth, rising higher in some places and lower in others. Bedrock depths taken from the test borings were used to help calibrate the profile's depth scale. B120 encountered bedrock at 2 meters, B119 at 1.4 meters, and B118 at 1.2 meters. The profile's interpreted bedrock line closely matches the depths at which the test borings encountered bedrock, except at boring B118 where the exact location of the test boring could not be identified because of snow cover. At this location the radar unit must have been pulled nearby the test boring and not actually over it.



Figure 16: Path of GPR within the woods

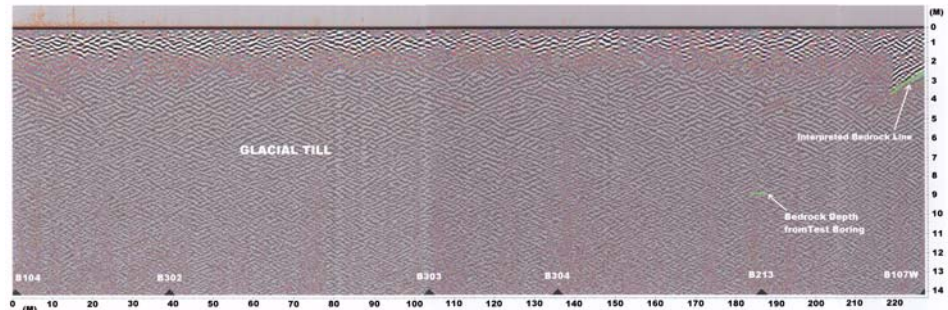


Figure 17: Test borings indicate that bedrock rises from below the profile bottom on the left to a depth of 3 meters at the right. The glacial till was absorbing the radar energy below 4 meters of depth

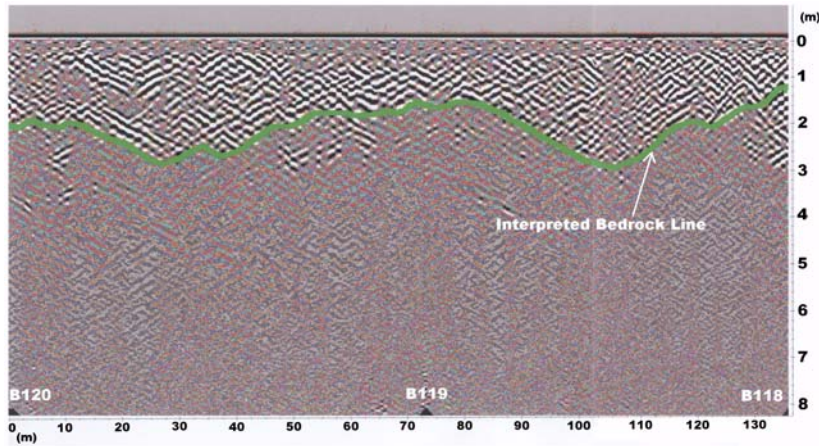


Figure 18: The interpreted bedrock line from the radar profile correlating well with the test boring data

Wilton-Milford Roadway Project

This project involved pushing back a roadway cut slope so the sight distance at an intersection could be increased. The depth to bedrock needed to be determined at an offset from the roadway centerline in order for appropriate planning to occur so the slope could be cut back. Specific challenges included having old “as-built” plans (Figure 19), no survey staked in the field, and the need to have results within a few days. Time constraints ruled out the possibility of mobilizing a drill rig and exposed bedrock at the corner of the intersection indicated that bedrock would be encountered within the limits of the project. To determine other locations along the slope where bedrock might be encountered, a couple of GPR profiles were collected parallel to the roadway alignment. A geological site reconnaissance revealed that the expected soil conditions would be sand over bedrock. Since project plans and survey were not available, an estimate was made as to how far the slope would be cut back. The depth to bedrock was unknown so the 100 MHz antenna was used for maximum depth penetration and velocity estimates were made to calibrate the depth scale. Figures 20 & 21 are photographs of the project site showing the cleared path for the radar unit and the estimated locations of the survey stationing.

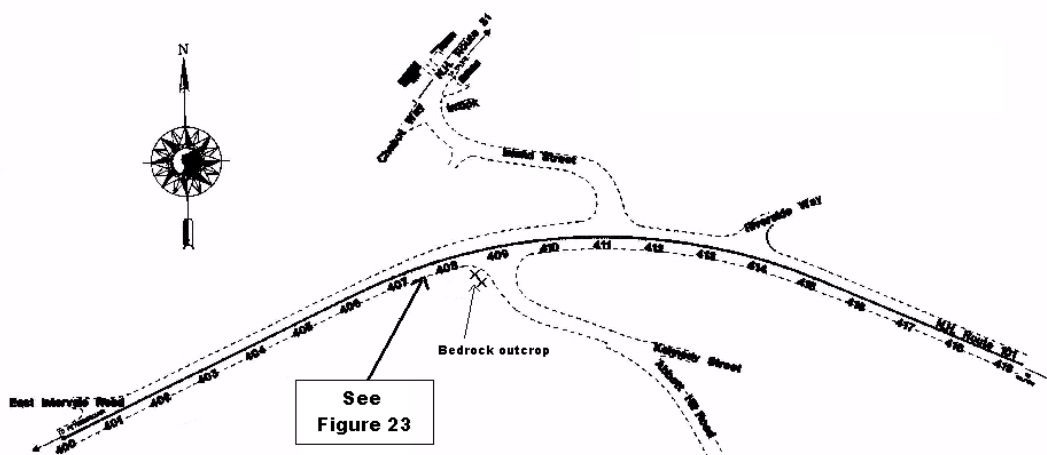


Figure 19: Copy of “as-built” plans minus some of the details



Figure 20: The path cut for collecting the GPR profile along the embankment and within the woods



Figure 21: The roadway embankment showing the estimated survey stationing from the “as-built” plans

Figure 22 is one of the profiles collected at the site. The green line represents the interpreted bedrock surface and the marks at the bottom of the profile are the estimated survey stationing from the old “as-built” plans. In order to help determine where bedrock was displaying on the profile the radar unit was started near the corner of the intersection where bedrock was very close to the ground surface. The interpreted bedrock line was drawn at the boundary between the two distinct surfaces shown on the profile, except at the beginning of the profile where our assumption of having bedrock close to the ground surface was used. During the construction phase of this project bedrock was encountered within the cut slope. Accurate elevations of the exposed bedrock surface were obtained and plotted on the cross sections with the original ground surface, the new ground surface, and the interpreted bedrock line (Figure 23). The cross section shown in Figure 23 displays how closely the interpreted bedrock line follows the actual bedrock surface measured during the construction phase of the project.

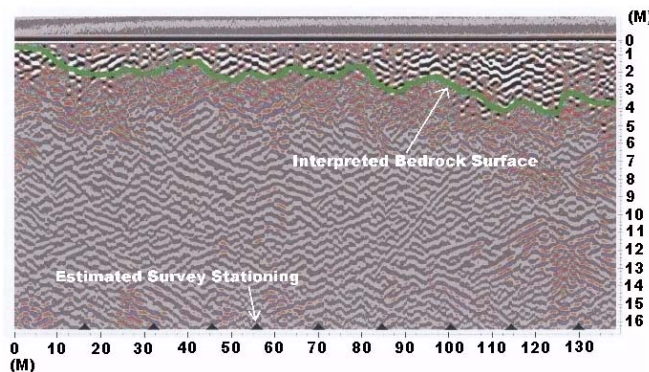


Figure 22: Interpreted bedrock line with the estimated survey stationing for the profile collected along the embankment

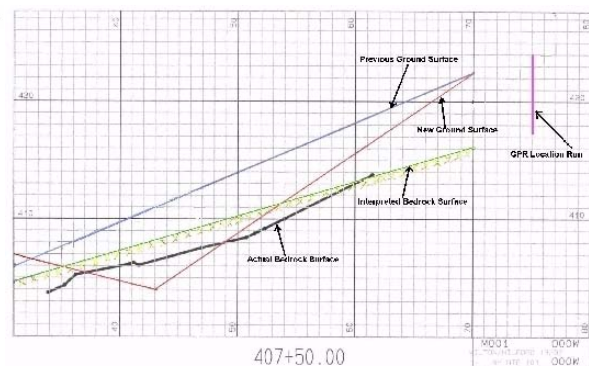


Figure 23: One of the final cross-sections showing the different surfaces and the actual location of where the GPR profile was collected

I-89 Sunapee Rest Area

Two weeks prior to bid advertisement, work within a rest area was added to a large interstate highway project. The additional work involved increasing the parking capacity of the rest area by cutting back a large unstable rock slope and rehabilitating the existing rest area building. Time constraints ruled out the possibility of conducting a geotechnical investigation so a site reconnaissance was done to estimate the amount of soil cover over the existing bedrock. During construction the rock cut's stability became a concern because vertical fractures and large seams, dipping towards the parking area, were uncovered. Figures 24 through 26 are photographs showing the dipping seams and the vertical fractures

along the face of the cut. Severely weathered rock and soil filled the seams and water was often flowing from them. A drill rig was mobilized in an attempt to locate the seams at a predetermined offset behind the face of the cut. A laser profiler was used to determine the elevation of the seams exposed on the face of the cut and GPR was used to locate the seams at areas between and adjacent to the test boring locations. The radar profiles were calibrated using the test boring and laser profiler data while existing survey data provided ground elevations for topography corrections above the cut.



Figure 24: Horizontal seam and vertical fracture

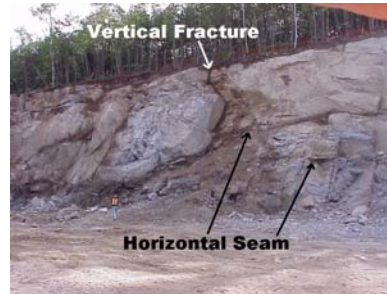


Figure 25: Horizontal seam and vertical fracture showing a detached slab



Figure 26: Frozen water flowing from horizontal seam

Figures 27 through 32 show the test boring logs, the laser profiles with seam locations, and the topography corrected GPR profiles, which start at the tops of the laser profiles and end at the test borings. By observing the depths where the seam intersects the face of the cut, where the test borings intersect the seam, and where the seam is detected on the profiles, it was deduced that the seam is continuous and dips towards the parking area. This geological investigation collected enough information to demonstrate that changes in the design of the cut slope and parking area were warranted to address the stability of the rock cut.

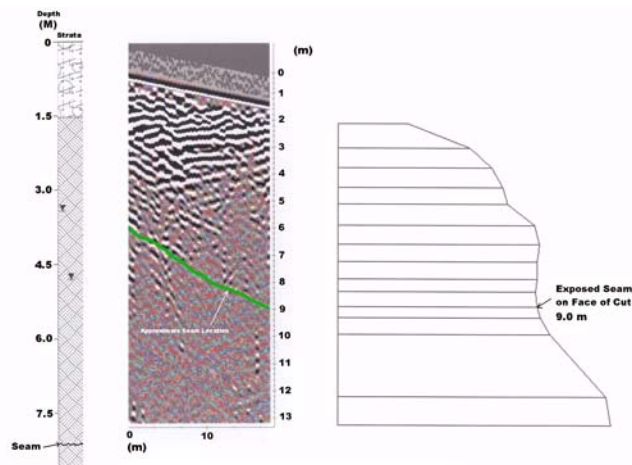


Figure 27: Test boring log, GPR and laser profiles for station 709+50

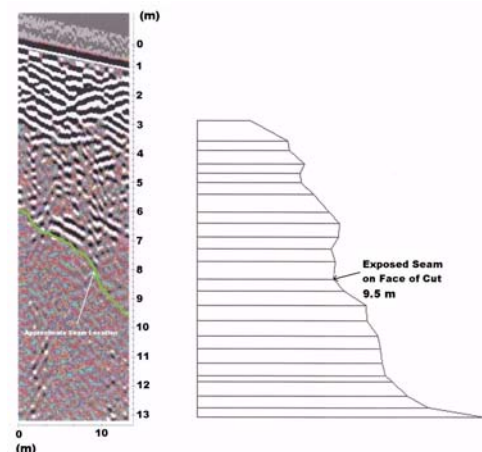


Figure 28: GPR and laser profiles for station 710+00

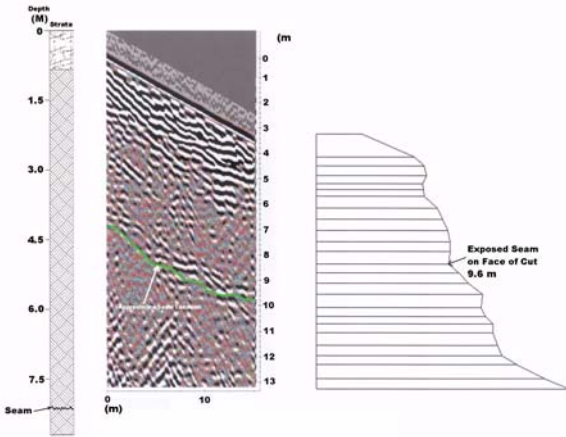


Figure 29: Test boring log, GPR and laser profiles for station 710+50

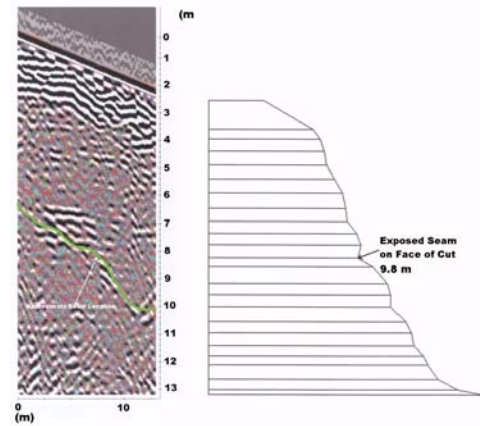


Figure 30: GPR and laser profiles for station 711+00

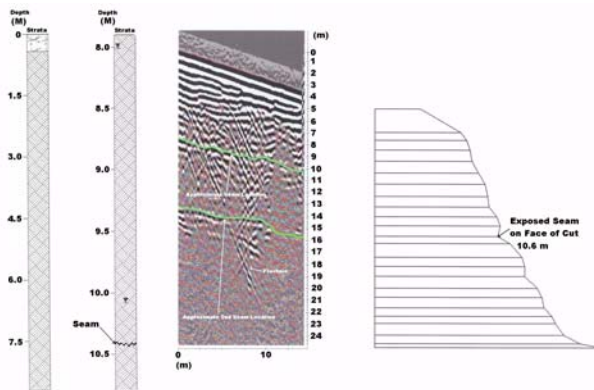


Figure 31: Test boring log, GPR and laser profiles for station 711+50

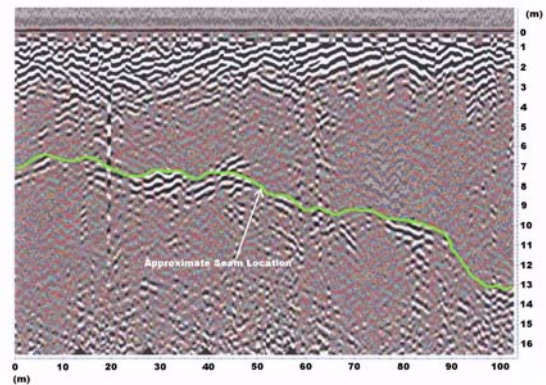


Figure 32: GPR profile parallel to the face of the cut depicting the seam

Hinsdale Bridge Project

This project involved acquiring a river bottom profile using GPR. The data collected with the radar unit was to supplement the existing test boring data. The existing plans and test boring data revealed water depths of one to twelve meters going across the width of the river. The test boring logs showed that silt, sand, gravel and glacial till was overlying bedrock between six and forty meters below the bottom of the river. To collect the profiles, the radar unit was placed in the bottom of a motorized fiberglass boat (Figures 33 & 34). A laser gun was used to measure an offset to the centerline of the new bridge from the existing bridge structure on each side of the river. A GPS was linked to the radar unit and used to track the location of where GPR profile data was collected. This allowed positional data to be attached to every trace in the profile and for a precise line to be drawn depicting where the radar unit collected its data (Figure 35).



Figure 33: Boat used to collect the river bottom profiles



Figure 34: The radar antenna was placed behind the seat



Figure 35: Photograph showing where the profiles were collected

Two profiles were collected at this site using the 100 MHz antenna. The data acquisition mode was changed from distance to time because the survey wheel was not being used as a trigger source for data collection. The river water was cloudy and contained a fair amount of sediment and visibility was limited to about a meter. Figure 36 shows the profile collected from the channel closest to the Vermont side of the river. The radar waves penetrated through the water down to a depth of about 7 meters and maybe another meter or two into the sediment. The river bottom is only visible at the beginning and at the end of the profile, which correlates to the edges of the river where the water depth is minimal. Towards the middle of the profile the depth of the water becomes greater than what the radar signal can penetrate and the river bottom is no longer visible. Figure 37 is the profile collected along the channel closest to the New Hampshire side of the river. Like the profile on the Vermont side, the river bottom is only visible at the beginning and at the end of the profile. Towards the middle of the profile the radar energy is attenuated before it reaches the bottom of the river. The high amount of suspended sediment in the river along with the water depth provide likely explanations for not detecting river bottom reflections away from the banks of the river.

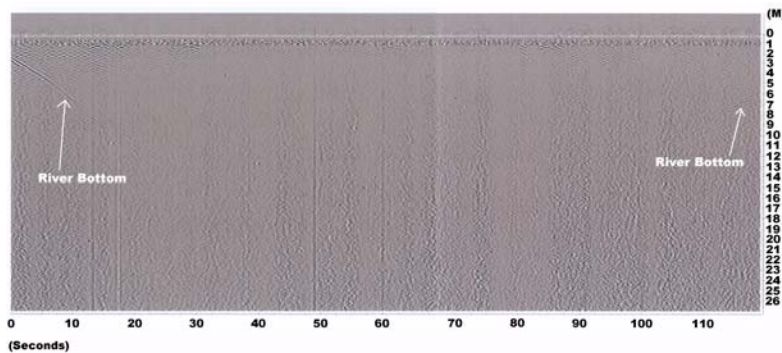


Figure 36: River bottom profile from VT side of river, going east to west. The river bottom is only visible on the sides of the river

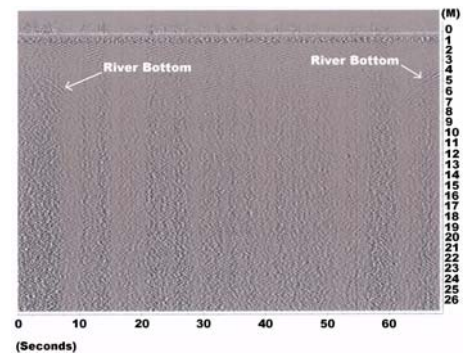


Figure 37: River bottom profile from NH side of river. The river bottom is only visible on the sides of the river

Hudson Roadway Project

This was a roadway improvement project that included the cutting back of an embankment and the placing of sewer lines beneath the roadway. Test borings revealed that bedrock would be encountered within the limits of the project so GPR was employed to help fill in the gaps between the test borings. Challenges included a heavy volume of traffic and an abundance of buried utilities. The test borings revealed that the soil conditions were silty sand over shallow bedrock.

Figure 38 is a photograph of the road depicting where the subsurface investigation was undertaken. A 783-meter profile was collected along the left-hand side of this road using the 100 MHz antenna. Figure 39 is a portion of the profile collected in the area of where the existing embankment will be cut back. The profile was collected at the base of the cut slope a few meters away from the test borings

locations and 2.5 meters lower in elevation. There were buried utilities along the base of the cut slope within a couple of meters from where the profile was collected. The 2.5-meter elevation difference was subtracted from the test boring data so the radar and test boring data could be compared. The profile appears to correlate with the test boring data at borings B106, B105 and B104 but does not correlate with the test boring data at borings B103, B102 and B101. At some of the locations between the test borings, the validity of the radar data appears to be questionable. The profile's interpreted bedrock line is solid where the correlation between the test boring and GPR data is good and dashed where the correlation is poor.



Figure 38: Route 102 in Hudson, NH

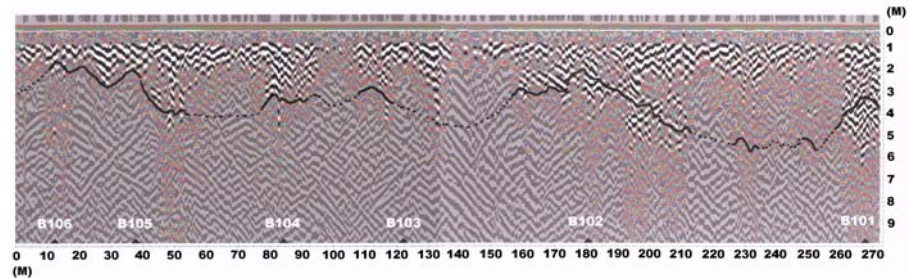


Figure 39: Profile along embankment, solid line indicates bedrock was confirmed with test borings, dashed lines are estimated bedrock surfaces

Claremont Roadway Project

This roadway project involved the enlargement of the intersection shown in figure 40. To determine what the soil and bedrock conditions were at this site a subsurface investigation was conducted by drilling test borings and collecting GPR profiles. The profiles that were collected off the roadway surface indicated that bedrock was shallow and nearby test borings confirmed this. These borings encountered bedrock along the left hand side of the road at 1.0 meter and along the right hand side of the road at 3.4 meters. To determine if bedrock would be encountered within the middle of the intersection several GPR profiles were collected. Traffic concerns eliminated the possibility of drilling test borings in the middle of the intersection for bedrock depth confirmation. Figure 41 is a profile collected by pulling the radar unit down the center of the road shown in figure 40. It starts on the pavement and goes onto the concrete median for a total length of 70 meters. When comparing the pavement section of the profile to that of the concrete section there is a distinct difference in signal penetration. Since this investigation was conducted during the spring it is believed that dissolved roadway salt inhibited the penetration of the radar signal into the pavement. The difference in signal penetration makes the interpretation of the profile extremely difficult.



Figure 40: Intersection in Claremont, NH

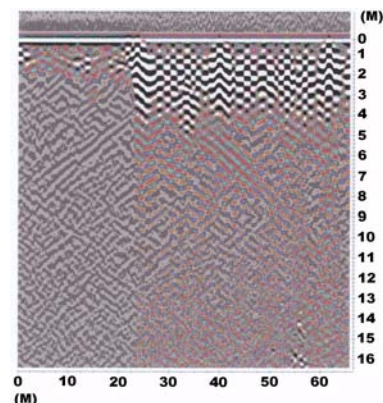


Figure 41: Intersection Profile. Notice profile change from asphalt to concrete

Hudson Roadway Void Project

This project was initiated because of an embankment failure along a relatively new section of roadway located on top of an embankment fill (Figure 42). On the other side of the road and opposite the embankment failure voids were opening up on the ground surface (Figure 43). To determine if the roadway was in danger of failing or if voids existed below the roadway surface a drill rig was mobilized to drill holes through the pavement and the radar unit was set up to collect GPR profiles. It became apparent that water could easily travel beneath the roadway surface and through the fill because wash water from the drilling operations emerged from around a drainage pipe located at the base of the embankment (Figure 44).



Figure 42: Embankment failure in Hudson, NH



Figure 43: Voids on opposite side of road to embankment failure



Figure 44: Test boring wash water emerging at base of embankment

The profiles shown in figures 45, 46 and 47 were collected using the 500 MHz antenna and the profile shown in figure 48 was collected using the 100 MHz antenna. The profiles in figures 45, 46 and 47 show the bottom of the roadway's base coarse material and a soil boundary layer a meter or two lower in elevation. The marks at the bottom of these profiles represent the test boring locations. The profiles going from B4 to B2 (Figure 45) and B3 to B1 (Figure 46) are perpendicular to the roadway alignment and the profile going from B2 to B1 (Figure 47) is parallel to the roadway alignment. The profile in figure 48 was run parallel to the roadway alignment, six meters from the edge of pavement and next to the surface voids that are shown in figure 43. The marks at the bottom of this profile represent the location of the surface voids. The test boring logs (Figure 49) indicate that silty fine sands with layers of clay and gravel compose most of the embankment fill. Riprap or larger stone was not found to be present anywhere within the embankment fill and neither GPR nor the test borings detected any subsurface voids. It appears that water flows from one side of the embankment fill to the other along the detected soil boundary and as it exits it washes out the side of the embankment.

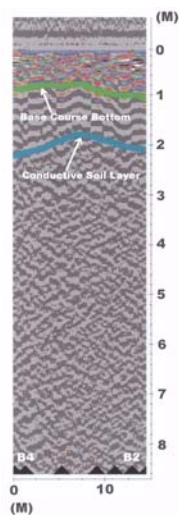


Figure 45: GPR profile

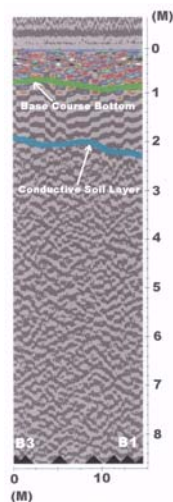


Figure 46: GPR profile

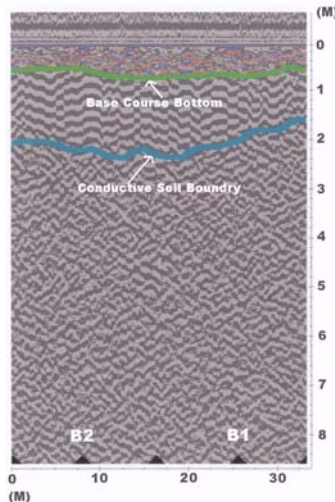


Figure 47: GPR profile



Figure 48: GPR profile

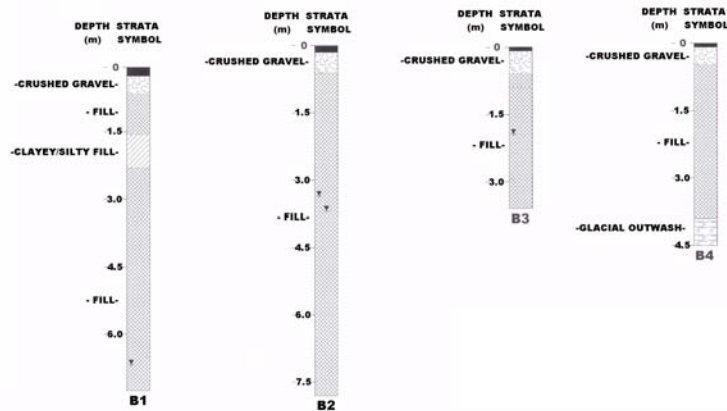


Figure 49: Test boring logs for the above GPR profiles (Figures 45-48)

Strengths And Weaknesses With Cost Effectiveness

The strengths associated with using GPR on subsurface investigations are significant. One or two people can collect information in a minimal amount of time. Equipment set-up is relatively simple and depending upon the existing ground surface, minimal preparation is needed. Buried utilities do not need to be located because GPR is non-destructive. The radar unit can access locations where a conventional drill rig could not or would have extreme difficulty accessing. The subsurface information that is collected through GPR is continuous, so a complete profile can be obtained as compared to test borings where only point information can be obtained.

The weaknesses associated with using GPR are also significant. If the existing ground surface is rough and thickly wooded, a chain saw may be required to clear a path for the radar unit to follow. Operating the laptop computer in temperatures below 32°F can be difficult, colder temperatures reduce the batteries' lifespan and make the mouse "touch pad" extremely difficult to use. Highly conductive soil types will absorb the radar signal leaving little reflected energy for the receiver to detect. Our research has found it uncommon to detect greater than two soil boundary layers because highly conductive or very thick soil layers often lie above the remaining soil layers or bedrock and absorb all the radar energy. Finally, calibrating the depth scale is difficult because signal velocities change as different soil types are encountered and many soil layers have variable elevations over the length of a profile.

When a project requires additional subsurface information, GPR is substantially faster and less expensive as compared to conventional test borings. The costs and time associated with re-mobilizing a drill rig and drilling additional test borings are quite significant. The amount of work a small geotechnical staff can complete is greatly increased when drill rigs can move onto new projects instead of re-mobilizing onto existing projects.

Summary

This research project was funded through New Hampshire's State Planning and Research (SP&R) money. It has helped the Department of Transportation understand how well GPR can supplement or replace conventional test borings. The eight projects described in this paper demonstrate how well GPR can work under favorable conditions and how ineffective it can be under unfavorable conditions. GPR cannot identify the composition of the surfaces it detects. For compositional analysis and depth scale calibration nearby test borings should be drilled.

GPR was successful in detecting the depth to bedrock on the Easton-Woodstock roadway project, the Wilton-Milford roadway project and at one of two locations on the Windham-Salem By-Pass project. GPR also had little difficulty detecting the seams and fractures within the bedrock on the I-89 Sunapee Rest Area project. Although GPR was able to obtain decent subsurface profiles on the Hudson roadway void project it did not detect any subsurface voids. It is possible that the radar unit could not differentiate

between the material filling the voids and the material surrounding the voids. It is also possible that the void sizes were beyond the resolution of the antenna or that the voids simply did not exist. GPR was unable to obtain a river bottom profile on the Hinsdale bridge project. The high amount of suspended sediment in the river, the depth of the water and the types of soil along the river bottom all contributed to the attenuation of the radar energy. GPR results on the Claremont and Hudson roadway projects were inconclusive. The profiles were hard to interpret because of discrepancies between the test boring data and the radar profiles. The attenuation of the radar energy due to dissolved roadway salt was also a problem on the Claremont roadway project. The radar unit ran into difficulties detecting greater than two distinct layers. This probably was due to the fact that conductive soil layers often lie above deeper soils or bedrock.

The eight projects described in this paper demonstrate that GPR can work well in different applications and in different locations throughout the state. They also demonstrate that when local geology is not conducive for this type of geophysical method, GPR falls short of providing detailed information. It is recommended that other geophysical techniques, possibly seismic refraction and resistivity, be used in conjunction with GPR. These additional techniques would provide greater flexibility in conducting subsurface investigations. By having more than one geophysical technique to draw from, local geology will have less of an impact in obtaining detailed subsurface information.

References

1. RAMAC/GPR Operating Manual, Version 3.0, July 1999.
2. MALA GeoScience, Inc., 2000, Introductory Training Course Manual For RAMAC/GPR.